ONR 312 EW D&I PROGRAM REVIEW
December 4-6, 2019

Beyond Smart: Optical Neural Networks for Intelligent Electronic Warfare

The highest slide classification of this briefing package is: UNCLASSIFIED

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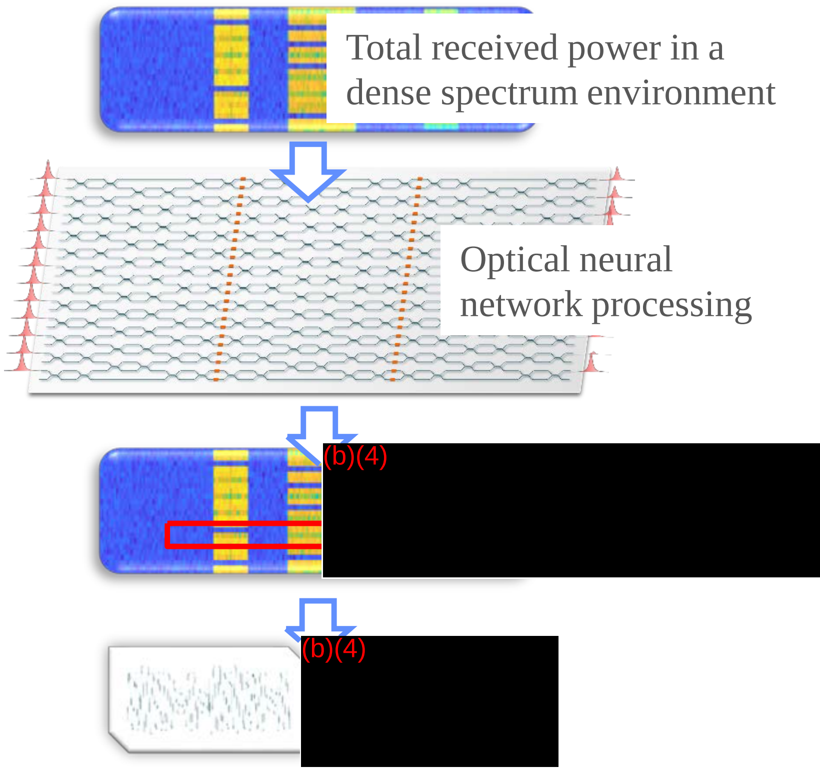
Technical Objective

Implement a multi-layer fully optical ONN to demonstrate low latency inference - 100’s of picoseconds (b)(4) [redacted]
(b)(4) [redacted]

Benefits

- **Improved effectiveness** of EW sensing and effects delivery due to *ultra-low latency* (~100s ps) accelerator. 10-100x improvement vs state-of-the art CPU/GPU.
- **Mobile/Edge deployment** form factor due to *integrated photonics*
- **Low power** neprocessingural network in a *photonic mesh*
- **Reduced** amount of data required for backhaul
- **Robust** operation in denied environments
- **Secure** platform for machine learning due to *edge computing* capability. No need to risk sending data long distance to a remote server for processing.



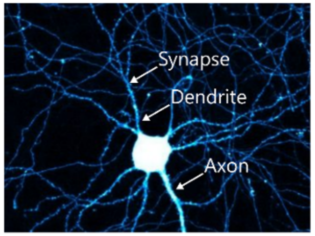
Technical Approach

Utilize the physics of coherent light interference which enables signal processing and computation in the optical domain by passing light through a photonic circuit. Implement Photonic Accelerator Circuit-based ONN leveraging these physics for ultra-low SWaP AI implementations.

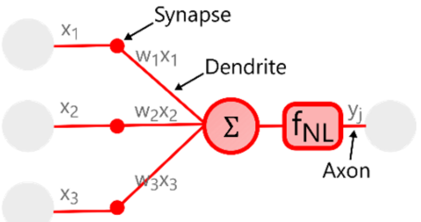
Artificial Neural Networks

- Consists of “neurons”
- Input neurons are connected to subsequent hidden and output layers
- Information propagates by a linear combination followed by the application of a non-linear activation function

Human neuron



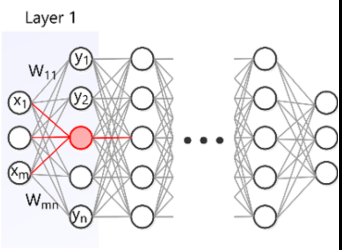
Artificial neuron



Current neural network hardware is **fundamentally limited in processing latency** due to *thermal constraints*.

- Faster clock speeds result in unmanageable heat density
- Parallelization for higher throughput come with high overhead and increased latency

Neural network



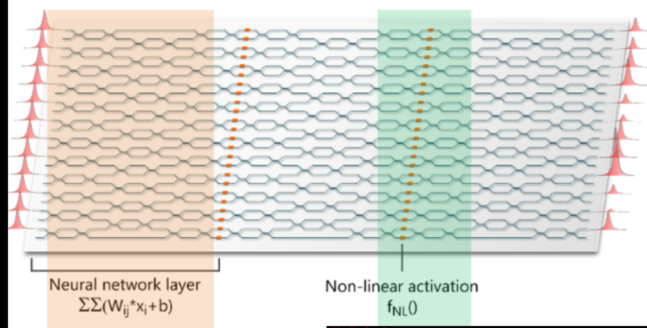
(b)(4)
[redacted]

Light passing through a constructed network performs operations, scales better than traditional CMOS transistors

Technical Details

2 key Elements in artificial neural networks: $Y = f_{NL}\left(\sum_{j=1}^{m}\sum_{i=1}^{n} W_{ij} \times x_i + b\right)$

(b)(4)
[redacted]



(b)(4)
[redacted]

Matrix multiplication: A mesh of interferometers forms the interconnection between photonic neurons. This static mesh performs arbitrary Multiply-and-Accumulate (MAC) operations at the speed of light and with little power.

1. Linear operator for MAC
$$D = U\Sigma V^*$$
2. Singular value decomposition
$$U(m), V(m) = \prod_{i=2}^{m}\prod_{j=1}^{i-1} T_{ij}(\theta,\phi)$$
3. Output of MZI
$$T_{ij} = \begin{bmatrix} e^{i\phi}sin\theta & e^{i\phi}cos\theta \\ cos\theta & -sin\theta \end{bmatrix}$$

(b)(4)
[redacted]

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Technical Details

Leverage neural networks to learn matched filters in presence of unknown channel effects and noise to determine symbol encoding features without expert understanding or estimation of the underlying waveform.

Received spectrum includes a dense environment of signals each with channel effects (rotation, linear mixing, time shifting, scaling, convolution, etc.)

(b)(4) [redacted]

	AlexNet	VGG	Optical-AlexNet	Optical-VGG
MACs	666M	15.3G	Equiv. to 666M	Equiv. to 15.3G
Bits per weight, etc.	16	16	16	16
Operations per second	$6\, x 10^{9}$	$4\, x\, 10^{9}$	Equiv. to $5\, x\, 10^{16}$	Equiv. to $1\, x\, 10^{17}$
Latency	100 ms	4000 ms	300 ps	700 ps
Power (mW)	300	300	<100	<100

Equivalent performance of ONN-enabled neural networks

(b)(4) [redacted]

Planned Progress

Planned Accomplishments Next 12 Months	Estimated Completion Date

(b)(4)

[redacted]

Potential Transition Path

(b)(4)
[redacted]

- Small form factor allows deployment on dedicated airborne EW platform such as the EA-18 Growler to the MQ4C Triton Broad Area Maritime System (BAMS) or smaller platforms such as the ScanEagle

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[redacted]

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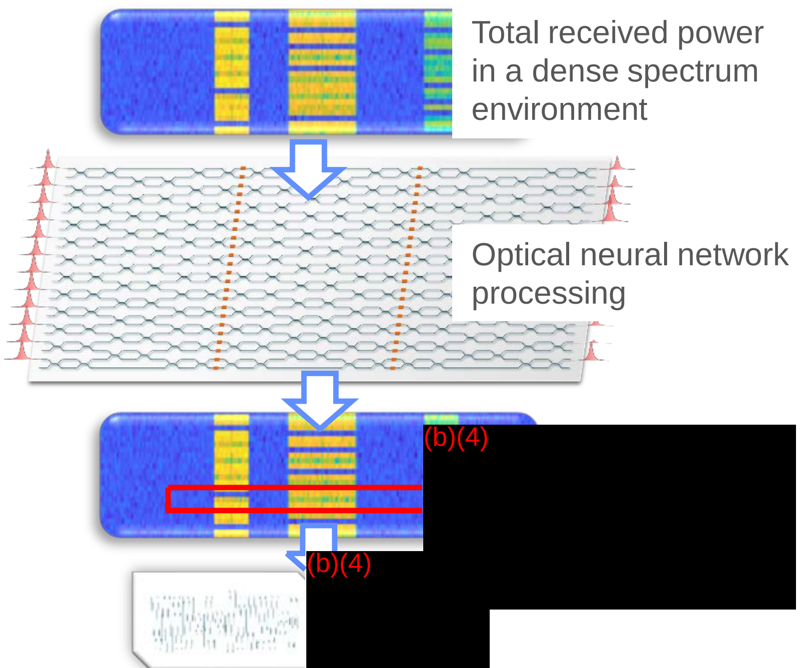
Objective

Implement a multi-layer fully Optical Neural Network (ONN) to demonstrate low latency inference - 100's of picoseconds - (b)(4) [redacted]

(b)(4) [redacted]



[redacted]

Warfighter Payoff

- **Improved effectiveness of** EW countermeasures due to *ultra-low latency* (~100s ps) accelerator
- **Reduced** amount of data required for backhaul – operation in denied environments
- **Secure** platform for machine learning due to *edge computing* capability. Processing performed locally.

Deliverables

(b)(4) [redacted]

- Final Test report

Milestones

FY20

- Phase I program kick off
- Design review

(b)(4) [redacted]

- Final report: performance of subsystem, roadmap, and planned OY1 activities
- Phase II program kickoff
- Design review

(b)(4) [redacted]

FY21

- Final report: performance of subsystem, roadmap, and planned OY2 activities
- Phase III program kickoff
- Design review

(b)(4) [redacted] integrated into prototype receiver

FY22

- Final report: performance of subsystem and transition plan into Navy EW systems